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DESCRIPTION

ELECTROMAGNETIC TRANSDUCER AND PORTABLE COMMUNICATION DEVICE

TECHNICAL FIELD

The present invention relates to an electroacoustic transducer for use in a portable communication device, e.g., a cellular phone or a pager, for reproducing an alarm sound or melody sound responsive to a received call and for reproducing voices and the like.

BACKGROUND ART

Figures **12A** and **12B** show a plan view and a cross-sectional view, respectively, of a conventional electroacoustic transducer **200** of an electromagnetic type (hereinafter referred to as an "electromagnetic transducer"). The conventional electromagnetic transducer **200** includes a cylindrical housing **107** and a disk-shaped yoke **106** disposed so as to cover the bottom face of the housing **107**. A center pole **103**, which forms an integral part of the yoke **106**, is provided in a central portion of the yoke **106**. A coil **104** is wound around the center pole **103**. Spaced from the outer periphery of the coil **104** is provided an annular magnet **105**, with an appropriate interspace maintained between the coil **104** and the inner periphery of the annular magnet **105** around the entire circumference thereof. The outer peripheral surface of the magnet **105** is abutted to the inner peripheral surface of the housing **107**. An upper end of the housing **107** supports a first diaphragm **100** so that an appropriate interspace exists between the first

diaphragm **100** and the magnet **105**, the coil **104**, and the center pole **103**. In a central portion of the first diaphragm **100**, a second diaphragm **101** which is made of a magnetic member is provided so as to be concentric with the first diaphragm **100**.

Now, the operation and effects of the above-described conventional electromagnetic transducer **200** will be described. In an initial state where no current flows through the coil **104**, a magnetic path is formed by the magnet **105**, the second diaphragm **101**, the center pole **103**, and the yoke **106**. As a result, the second diaphragm **101** is attracted toward the magnet **105** and the center pole **103**, up to a point of equilibrium with the elastic force of the first diaphragm **100**. If an alternating current flows through the coil **104** in this state, an alternating magnetic field is generated in the aforementioned magnetic path, so that a driving force is generated on the second diaphragm **101**. Such a driving force generated on the second diaphragm **101** causes the second diaphragm **101** to be displaced from its initial state, along with the fixed first diaphragm **100**, due to an interaction with an attraction force which is generated by the magnet **105** and the driving force. The vibration caused by such displacement transmits sound.

Figure **13** illustrates a characteristic curve of the driving force generated on the second diaphragm **101** of the electromagnetic transducer **200**. The vertical axis of the graph represents driving force, whereas the horizontal axis of the graph represents a distance from the center pole **103** to the second diaphragm **101** (i.e., a "magnetic gap value"). As seen from Figure 13, once

the magnetic gap value has reached a certain value (i.e., about 0.4 mm in this exemplary case), the driving force thereafter decreases in inverse proportion to the magnetic gap value. In other words, although there is a need to secure a large amplitude (and therefore a large magnetic gap value) for obtaining a high sound pressure level and enabling reproduction of low-frequency ranges, such a large magnetic gap value inevitably leads to a reduced driving force, which defeats the purpose of obtaining a high sound pressure level. On the other hand, in Figure 13, the reduced driving force in the neighborhood of the center pole **103** is accounted for by the second diaphragm **101** experiencing magnetic saturation.

DISCLOSURE OF THE INVENTION

According to one aspect of the present invention, there is provided an electromagnetic transducer including: a first diaphragm; a second diaphragm provided in a central portion of the first diaphragm, the second diaphragm comprising a magnetic material having a first opening in a central portion thereof; a yoke disposed so as to oppose the first diaphragm; a center pole disposed between the yoke and the first diaphragm, wherein the center pole has a shape which allows insertion into the first opening; a coil disposed so as to surround the center pole; and a first magnet disposed so as to surround the coil.

In accordance with such an electromagnetic transducer, it is possible to maintain a high driving force even when a magnetic gap along the height direction

is increased, by merely altering the configuration of the existing components without introducing additional components. Thus, a high sound pressure level and low-frequency range reproduction is realized.

In one embodiment of the invention, the first diaphragm has a second opening in which the center pole can be inserted.

In another embodiment of the invention, an upper face of the center pole is level with or higher than a lower face of the second diaphragm.

In accordance with such an electromagnetic transducer, a substantially constant distance can be maintained between the center pole and the second diaphragm even when the electromagnetic transducer has an amplitude of vibration. As a result, a stable driving force can be obtained.

In still another embodiment of the invention, the electromagnetic transducer further includes a first thin magnetic plate disposed between the first magnet and the first diaphragm.

In accordance with such an electromagnetic transducer, an alternating magnetic flux can be efficiently transmitted onto the second diaphragm. As a result, the driving force can be enhanced, thereby providing a high sound pressure level.

In still another embodiment of the invention, the center pole has a diameter which varies along a height

direction thereof.

In still another embodiment of the invention, the diameter of the center pole varies in such a manner as to represent a quadratic curve with respect to the height of the center pole.

In accordance with such an electromagnetic transducer, variation in the magnetic resistance of the magnetic path associated with the position of the second diaphragm can be minimized.

In still another embodiment of the invention, the second diaphragm has a larger thickness at an inner periphery than at an outer periphery thereof.

In still another embodiment of the invention, the second diaphragm is turned up or down at an inner periphery thereof so as to have a substantially L-shaped cross section.

In accordance with such an electromagnetic transducer, the second diaphragm and the center pole oppose each other in an increased area, so that it is possible to increase the driving force generated on the second diaphragm.

In still another embodiment of the invention, the electromagnetic transducer further includes a cover for covering the first opening in the second diaphragm.

In still another embodiment of the invention, the cover is integral with the first diaphragm.

In accordance with such an electromagnetic transducer, it is possible to avoid a decrease in the sound pressure level due to an escape of air.

In still another embodiment of the invention, the electromagnetic transducer further includes a second magnet provided so as to be on an opposite side of the second diaphragm from the yoke.

In accordance with such an electromagnetic transducer, the use of the second magnet serves to reduce the density of the magnetic flux that is generated within the second diaphragm by the first magnet, so that more alternating magnetic flux can be transmitted into the second diaphragm. The attraction force generated within the second diaphragm can be also cancelled, whereby the first diaphragm can be placed in a state of equilibrium.

In still another embodiment of the invention, the electromagnetic transducer further includes a second thin magnetic plate provided so as to be on an opposite side of the second magnet from the yoke.

In accordance with such an electromagnetic transducer, the second magnet can be allowed to function efficiently, so that it becomes possible to reduce the size of the second magnet.

In still another embodiment of the invention, the electromagnetic transducer further includes a first housing for supporting the first diaphragm.

In still another embodiment of the invention, the electromagnetic transducer further includes a second housing for supporting the second magnet.

According to another aspect of the present invention, there is provided a portable communication device incorporating any one of the aforementioned electromagnetic transducers.

In one embodiment of the invention, the portable communication device further includes an antenna for receiving radiowaves and a transmission/reception circuit for converting the radiowaves into a voice signal, wherein the electromagnetic transducer reproduces the voice signal.

According to the present invention, a portable communication device capable of reproducing an alarm sound or melody sound, voices, and the like can be realized.

In accordance with an electromagnetic transducer of the present invention, a second diaphragm is provided which has an annular shape with an opening in a central portion thereof, whereby the mass of the entire vibrating system can be reduced. Since the annular shape of the second diaphragm prevents the second diaphragm from coming into contact with a center pole during vibration, the center pole may have an increased height. Thus, the present invention can provide an electromagnetic transducer which is capable of producing a high sound pressure level and reproducing low-frequency ranges, while allowing for a substantially smaller magnetic gap

value and a stronger driving force to be generated on the second diaphragm than is conventionally possible.

Thus, the invention described herein makes possible the advantages of (1) providing an electromagnetic transducer which is capable of producing a high sound pressure level and reproducing low-frequency ranges, while allowing for a substantially smaller magnetic gap value and a stronger driving force to be generated on a second diaphragm than is conventionally possible; and (2) providing a portable communication device incorporating the same.

These and other advantages of the present invention will become apparent to those skilled in the art upon reading and understanding the following detailed description with reference to the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure **1A** is a cross-sectional view illustrating an electromagnetic transducer according to Example 1 of the present invention.

Figure **1B** is a plan view illustrating a first diaphragm in the electromagnetic transducer according to Example 1 of the present invention.

Figure **1C** is a plan view illustrating a second diaphragm in the electromagnetic transducer according to Example 1 of the present invention.

Figure **1D** is a plan view illustrating a first thin magnetic plate in the electromagnetic transducer

according to Example 1 of the present invention.

Figure **2** is a magnetic flux vector diagram of the electromagnetic transducer according to Example 1 of the present invention.

Figure **3** is a cross-sectional view illustrating the electromagnetic transducer according to Example 1 of the present invention.

Figure **4A** is a cross-sectional view illustrating an electromagnetic transducer according to Example 2 of the present invention.

Figure **4B** is a plan view illustrating a second magnet in the electromagnetic transducer according to Example 2 of the present invention.

Figure **5** is a magnetic flux vector diagram of the electromagnetic transducer according to Example 2 of the present invention.

Figure **6** is a graph illustrating the characteristics of an attraction force generated on a second diaphragm in the electromagnetic transducer according to Example 2 of the present invention.

Figure **7** is a graph illustrating the characteristics of a driving force generated on a second diaphragm in the electromagnetic transducer according to Example 2 of the present invention.

Figure **8A** is a cross-sectional view illustrating

an electromagnetic transducer according to Example 3 of the present invention.

Figure **8B** is a plan view illustrating a second thin magnetic plate in the electromagnetic transducer according to Example 3 of the present invention.

Figure **9** is a magnetic flux vector diagram of the electromagnetic transducer according to Example 3 of the present invention.

Figure **10** is a partially-cutaway perspective view of a cellular phone incorporating an electromagnetic transducer according to Example 4 of the present invention.

Figure **11** is a block diagram illustrating the structure of the cellular phone incorporating an electromagnetic transducer according to Example 4 of the present invention.

Figure **12A** is a plan view illustrating a conventional electromagnetic transducer.

Figure **12B** is a cross-sectional view illustrating a conventional electromagnetic transducer.

Figure **13** illustrates the characteristics of a driving force generated on a second diaphragm in a conventional electromagnetic transducer.

BEST MODES FOR CARRYING OUT THE INVENTION

Hereinafter, the present invention will be

described by way of illustrative examples, with reference to the accompanying figures.

(Example 1)

An electromagnetic transducer **1000** according to Example 1 of the present invention will be described with reference to Figures **1A**, **1B**, **1C**, **1D**, and **2**.

Figure **1A** is a cross-sectional view illustrating the electromagnetic transducer **1000** according to Example 1 of the present invention. Figure **2** is a magnetic flux vector diagram of the electromagnetic transducer **1000** according to Example 1 of the present invention. The magnetic flux vector diagram of Figure **2** only illustrates one of the two halves of the electromagnetic transducer **1000** with respect to a central axis (shown at the left of the figure).

As shown in Figure **1A**, the electromagnetic transducer **1000** according to Example 1 of the present invention includes a cylindrical first housing **7** and a yoke **6** (having a disk shape) disposed so as to cover the bottom face of the first housing **7**. A center pole **3**, which may form an integral part of the yoke **6**, is provided in a central portion of the yoke **6**. A coil **4** is wound around the center pole **3**. Spaced from the outer periphery of the coil **4** is provided an annular first magnet **5**, with an appropriate interspace maintained between the coil **4** and the inner periphery of the annular first magnet **5** around the entire circumference thereof. An appropriate interspace is maintained between the outer peripheral surface of the first magnet **5** and the inner peripheral surface of the first housing **7** around the

entire circumference thereof. An upper end of the first housing 7 supports a first diaphragm 1, which is composed of an annular non-magnetic member as shown in the plan view of Figure 1B, in such a manner as to allow vibration of the first diaphragm 1. An appropriate interspace exists between the first diaphragm 1 and the coil 4, and between the first diaphragm 1 and the center pole 3. In a central portion of the first diaphragm 1, a second diaphragm 2 which is composed of an annular magnetic member is provided so as to be concentric with the first diaphragm 1. The second diaphragm 2 has an opening in a central portion as shown in the plan view of Figure 1C. In the central portion of the second diaphragm 2, a cover 13 (Figure 1A) is provided so as to cover the opening in the second diaphragm 2. The center pole 3 is shaped so as to be capable of being inserted into the opening in the second diaphragm 2.

A first thin magnetic plate 11, having an annular shape as shown in the plan view of Figure 1D, is provided on a face of the first magnet 5 opposing the first diaphragm 1. On the inner peripheral surface of the first magnet 5, a concave portion for receiving the first thin magnetic plate 11 is provided. A plurality of air holes 8 are formed at predetermined intervals along the circumferential direction in the yoke 6 for allowing the space between the first diaphragm 1 and the yoke 6 to communicate with the exterior space lying outside the space between the first diaphragm 1 and the yoke 6. Each air hole 8 allows existing between the first diaphragm 1 and the yoke 6 to be released to the exterior so as to reduce the acoustic load on the first diaphragm 1.

According to the present example of the invention, PEN (polyethylene naphthalate), which is a non-magnetic material, can be used as a material of the first diaphragm **1**, with a thickness of about 38 μm, for example. A permalloy is used as a material of the second diaphragm **2**, with a thickness of about 50 μm, for example. The upper face of the center pole **3** is level with the upper face of the second diaphragm **2**. Alternatively, the upper face of the center pole **3** may be higher than the lower face of the second diaphragm **2**.

Next, the operation and effects of the electromagnetic transducer **1000** having the above-described structure will be described.

In an initial state where no current flows through the coil **4**, a first magnetic path is formed by the first magnet **5**, the first thin magnetic plate **11**, the second diaphragm **2**, the center pole **3**, and the yoke **6**, as shown in Figure **2**. The first diaphragm **1** is omitted from the illustration in Figure **2** because a non-magnetic resin material is used for the first diaphragm **1** according to the present example of the invention.

In the above structure, a downward attraction force is generated on the second diaphragm **2**, causing the second diaphragm **2** and the first diaphragm **1** (Figure **1A**) to be displaced.

Next, if an alternating current flows through the coil **4** in this state, an alternating magnetic field is generated, and a driving force is generated on the second diaphragm **2**. Such a driving force generated on the

second diaphragm **2** causes the second diaphragm **2** to be displaced from its initial state, along with the fixed first diaphragm **1**. The vibration caused by such displacement transmits sound.

In accordance with the electromagnetic transducer **1000**, the center pole **3** is provided so as to penetrate through the opening in the central portion of the second diaphragm **2**. In order to ensure that a peak in the driving force generated on the second diaphragm **2** substantially coincides with a zero point (i.e., the position of the second diaphragm **2** when no current flows through the coil **4**), it is preferable that the upper face of the center pole **3** is level with the upper face of the second diaphragm **2**. Therefore, the electromagnetic transducer **1000** shown in Figures **1A** and **2** has a narrower magnetic gap between the second diaphragm **2** and the center pole **3** in the first magnetic path than the magnetic gap between the second diaphragm **101** and the center pole **103** in the conventional electromagnetic transducer **200** shown in Figure **12B**. As a result, the magnetic resistance in the entire first magnetic path of the electromagnetic transducer **1000** is reduced, so that the electromagnetic transducer **1000** experiences, if at all, a smaller decrease in the driving force than the conventional electromagnetic transducer **200**. Therefore, even in the case where the distance between the first magnet **5** and the second diaphragm **2** is increased to obtain a large amplitude range, it is still possible to secure a sufficient driving force for obtaining a high sound pressure level. In addition, the annular configuration of the second diaphragm **2** contributes to a decrease in the mass of the vibrating system, which makes for further

enhancement of the sound pressure level.

In the present example, the cover **13** covers the opening in the second diaphragm **2** so as to entirely prevent sound from being emitted through an interspace between the center pole **3** and the second diaphragm **2**. However, the cover **13** can be omitted in the case where interspaces between the center pole **3** and the second diaphragm **2** and the air holes **8** are of such a relationship that substantially no sound escapes from the interspace between the center pole **3** and the second diaphragm **2**. The cover **13** may be formed as an integral part of the first diaphragm **1**, or as a separate member.

Although according to the present example of the invention a resin material is used for the first diaphragm **1** for molding facility, it is also applicable to employ a metal material (e.g., titanium) from the perspective of heat resistance. A magnetic material may be used for the first diaphragm **1**. The first diaphragm **1** may be of a disk shape.

Although the first thin magnetic plate **11** is provided on the first magnet **5** according to the present example of the invention, the first thin magnetic plate **11** may be omitted in the case where sufficient driving force can be obtained with the first magnet **5** alone, or under stringent spatial constraints.

Although the center pole **3** is illustrated as having a constant diameter according to the present example of the invention, the center pole **3** may have a varying diameter along its height direction. As an

example, a cross-sectional view is given in Figure 3 showing an electromagnetic transducer **1001** including a center pole **3'** whose diameter decreases toward the yoke **6**. Other than the center pole **3'**, the electromagnetic transducer **1001** has the same component elements as those of the electromagnetic transducer **1000** (shown in Figure **1A**).

In accordance with the electromagnetic transducer **1001**, the magnetic gap between the second diaphragm **2** and the center pole **3'** increases as the second diaphragm **2** is displaced in a downward direction, whereby the decrease in the driving force due to magnetic saturation (illustrated with reference to Figure **13**) can be reduced. The diameter of the center pole **3'** may vary along its height direction in such a manner as to represent a quadratic curve with respect to the height, as shown in Figure 3.

(Example 2)

An electromagnetic transducer **2000** according to Example 2 of the present invention will be described with reference to Figures **4A**, **4B**, and **5**.

Figures **4A** and **5** are a cross-sectional view and a magnetic flux vector diagram, respectively, illustrating the electromagnetic transducer **2000** according to Example 2 of the present invention. The magnetic flux vector diagram of Figure **5** only illustrates one of the two halves of the electromagnetic transducer **2000** with respect to a central axis (shown at the left of the figure).

In accordance with the electromagnetic transducer **2000** shown in Figure **4A**, a second magnet **9**, having an annular shape as shown in the plan view of Figure **4B**, is provided above the second diaphragm **2** with a magnetic gap therebetween. The second magnet **9** is supported by a second housing **10**. Holes **12** for allowing sound generated by the first and second diaphragms **1** and **2** and the cover **13** to be emitted to the exterior space lying outside the second housing **10** are provided in the second housing **10**. The second magnet **9** is magnetized along its height direction, as is the first magnet **5**. Otherwise, the electromagnetic transducer **2000** has the same structure as that of the electromagnetic transducer **1000** shown in Figure 1.

Next, the operation and effects of the electromagnetic transducer **2000** having the above-described structure will be described.

As in the case of Example 1 (Figure **2**), a first magnetic path is formed by the first magnet **5**, the first thin magnetic plate **11**, the second diaphragm **2**, the center pole **3**, and the yoke **6**, as shown in Figure **5**. In addition, a second magnetic path is formed by the second magnet **9** and the second diaphragm **2**, according to the present example of the invention.

In an initial state where no current flows through the coil **4**, a downward attraction force generated through the first magnetic path and an upward attraction force generated through the second magnetic path are at equilibrium on the second diaphragm **2**. Therefore, the first diaphragm **1** undergoes substantially no

displacement due to the first magnetic path.

Next, if an alternating current flows through the coil **4** in this state, an alternating magnetic field is generated, and a driving force is generated on the second diaphragm **2**. Such a driving force generated on the second diaphragm **2** causes the second diaphragm **2** to be displaced from its initial state, along with the fixed first diaphragm **1**. The vibration caused by such displacement transmits sound.

Figure **6** is a graph illustrating the attraction force generated on the second diaphragm **2**, with respect to the case where the second magnet **9** is provided and the case where the second magnet **9** is not provided. The vertical axis represents attraction force, whereas the horizontal axis represents a distance from a zero point to the second diaphragm **2**. As used herein, the "zero point" refers to a position taken by the second diaphragm **2** when the downward and upward attraction forces applied by the first and second magnets **5** and **9**, respectively, on the second diaphragm **2** are at equilibrium. The solid line in the graph represents the case where the second magnet **9** is provided; and the broken line in the graph represents the case where the second magnet **9** is not provided.

As shown in Figure **6**, in the case where the second magnet **9** is not provided, the attraction force always has a positive value because the second diaphragm **2** is attracted to the first magnet **5**.

On the other hand, in the case where the second

magnet **9** is provided, an additional attraction force is generated in the opposite direction from the first magnet **5**. As a result, the attraction force can properly take either positive or negative values, with respect to the zero point at which the upward and downward attraction forces are at equilibrium on the second diaphragm **2**.

According to the present example, the thickness of the second diaphragm **2** is as thin as about 50 μm, so as to facilitate magnetic saturation. As a result, the drastic increase in the attraction force which would otherwise occur as the second diaphragm **2** approaches the first magnet **5** is subdued. Due to such configuration, the attraction force presents a substantially linear characteristic curve with respect to the distance from the zero point, as shown in Figure **6**.

As a result, it is possible to reduce the stiffness of the entire system, which can be calculated as a difference between the elastic force of the first diaphragm 1 and the attraction force. Accordingly, the resonance frequency of the system, which is determined by the stiffness, can be lowered.

If the elastic force characteristics of the first diaphragm 1 are similar to the attraction force characteristics (i.e., if the first diaphragm 1 has linear elastic force characteristics), the entire system has a constant stiffness independent of the position of the second diaphragm **2**. As a result, fluctuation in the resonance frequency due to different voltages levels being applied is prevented, and harmonic distortion is minimized.

Figure 7 is a graph illustrating the driving force generated on the second diaphragm **2**, with respect to the case where the second magnet **9** is provided and the case where the second magnet **9** is not provided. The vertical axis represents driving force, whereas the horizontal axis represents a distance of the second diaphragm **2** from the first magnet **5**. As in Figure **6**, the solid line in the graph represents the case where the second magnet **9** is provided; and the broken line in the graph represents the case where the second magnet **9** is not provided.

In Figure **7**, in the case where the second magnet **9** is not provided, magnetic saturation occurs due to the use of the relatively thin second diaphragm **2**, so that a sufficient driving force cannot be obtained.

Therefore, by the addition of the second magnet **9**, the magnetic flux generated by the first magnet **5** and acting on the second diaphragm **2** can be canceled, so that magnetic saturation is alleviated. Consequently, an alternating magnetic flux, which provides the driving force, can efficiently flow into the second diaphragm **2**, resulting in a large driving force. Thus, a sufficient driving force can be obtained despite the use of the relatively thin second diaphragm **2**, which would otherwise be susceptible to magnetic saturation. The reduced thickness of the second diaphragm **2** also contributes to a decrease in the mass of the vibrating system, which makes for further enhancement of the sound pressure level.

Although the thickness of the second diaphragm **2** according to the present example of the invention is as

thin as about 50 μm in order to facilitate magnetic saturation, it is also applicable to employ a relatively thick second diaphragm **2** without considering magnetic saturation. In such a case, decrease in the driving force in the neighborhood of the first magnet **5** due to magnetic saturation (illustrated in Figure **7**) will not occur; therefore, the use of a relatively thick second diaphragm **2** is effective in embodiments of the invention where the second diaphragm **2** is used in the neighborhood of the first magnet **5**. Similar effects can be obtained by using a material having a relatively large saturation magnetization level, e.g., pure iron, as the material for the second diaphragm **2**.

Although the second housing **10** is provided for supporting the second magnet **9** according to the present example of the invention, in applications where the electromagnetic transducer **2000** is incorporated in a cellular phone, for example, the second magnet **9** may be embedded within the housing of the cellular phone. Thus, the same housing can be shared by the electromagnetic transducer **2000** and the cellular phone.

(Example 3)

An electromagnetic transducer **3000** according to Example 3 of the present invention will be described with reference to Figures **8A**, **8B**, and **9**.

Figure **8A** and **9** are a cross-sectional view and a magnetic flux vector diagram, respectively, illustrating the electromagnetic transducer **3000** according to Example 3 of the present invention. The magnetic flux vector diagram of Figure **9** only illustrates one of the

two halves of the electromagnetic transducer **3000** with respect to a central axis (shown at the left of the figure).

The electromagnetic transducer **3000** shown in Figure **8A** includes a second diaphragm **22** having an L-shaped cross section at its inner periphery, an annular second magnet **29** which is provided above the second diaphragm **22** with a magnetic gap therebetween, and a second thin magnetic plate **24**, having an annular shape as shown in the plan view of Figure **8B**.

The second magnet **29** is supported by a second housing **20**. The second housing **20** has a concave portion for receiving the second thin magnetic plate **24**. Holes **32** for allowing sound generated by the first and second diaphragms **1** and **22** to be emitted to the exterior space lying outside the second housing **20** are provided in the second housing **20**. Otherwise, the electromagnetic transducer **3000** has the same structure as that of the electromagnetic transducer **2000** according to Example 2 of the present invention shown in Figure **4A**.

Since the second thin magnetic plate **24** is provided on the upper face of the second magnet **29**, a second magnetic path is formed by the second magnet **29**, the second thin magnetic plate **24**, and the second diaphragm **22**, as shown in Figure **9**. The first magnet **5** and the second magnet **29** provide the same effects as those of the first magnet **5** and the second magnet **9** (Figure **4A**) according to Example 2 of the present invention. The energy product of the second magnet **29**is adjusted so that the magnetic flux from the second magnet **29** will be transmitted to the second thin magnetic plate **24** to form

an appropriate magnetic path.

Since the second diaphragm **22** has an L-shaped cross section at its inner periphery as shown in Figure **8A**, the magnetic flux concentrates at the inner periphery of the second diaphragm **22**, so that magnetic flux can be efficiently transmitted between the second diaphragm **22** and the center pole **3**. The second diaphragm **22** may have any cross-sectional shape which presents a larger thickness at the inner periphery than at the outer periphery, e.g., a triangular or trapezoidal cross section. Two or more diaphragms having different outer diameters may be stacked to form the second diaphragm **22**. Since the second diaphragm **22** and the center pole **3** oppose each other in an increased area due to the increased thickness of the second diaphragm **22** at its inner periphery, it is possible to increase the air resistance between the second diaphragm **22** and the center pole **3**. In such a case, the cover **13** can be omitted from the electromagnetic transducer **3000**.

The second thin magnetic plate **24** provided as shown in Figure **8A** allows the magnetic flux from the second magnet **29** to be transmitted via the second thin magnetic plate **24**, so that the second magnetic path attains a reduced magnetic resistance. As a result, the energy product of the second magnet **29** can be reduced as compared to the case where the second thin magnetic plate **24** is not provided. Furthermore, since the magnetic flux from the second magnet **29** is transmitted into the second thin magnetic plate **24**, the amount of magnetic flux leaking to the outside of the electromagnetic transducer **3000** can be reduced.

In accordance with the electromagnetic transducer **3000** of the present example, the same attraction force that is provided by a structure which lacks the second thin magnetic plate **24** (e.g., the electromagnetic transducer **2000** shown in Figure **4A**) under the conditions that the second magnet **9** has an energy product of about 26 MGOe and a thickness of about 0.7 mm can be achieved under the conditions that the second magnet **29** has an energy product of about 22 MGOe and a thickness of about 0.5 mm, due to the addition of the second thin magnetic plate **24**.

The first diaphragm **1** in each of the electromagnetic transducers **1000**, **1001**, **2000**, and **3000** described in Examples 1 to 3 of the present invention is configured such that a portion of its annular shape is raised in a direction perpendicular to the direction of its diameter. However, the first diaphragm **1** is not limited to such a shape, but may instead have a flat cross section.

(Example 4)

As Example 4 of the present invention, a cellular phone **61** will be described with reference to Figures **10** and **11**, as one implementation of a portable communication device incorporating the electromagnetic transducer according to the present invention. Figure **10** is a partially-cutaway perspective view of the cellular phone **61** according to Example 4 of the present invention. Figure **11** is a block diagram schematically illustrating the structure of the cellular phone **61**.

The cellular phone **61** includes a housing **62**, which has a soundhole **63**, and an electromagnetic transducer **64**. As the electromagnetic transducer **64** to be incorporated in the cellular phone **61**, any one of the electromagnetic transducers **1000**, **1001**, **2000**, and **3000** illustrated in Examples 1 to 3 can be employed. The electromagnetic transducer **64** is disposed in such an orientation that its diaphragm opposes the sound hole **63**.

As shown in Figure 11, the cellular phone **61** further includes an antenna **150**, a transmission/reception circuit **160**, a call signal generation circuit **161**, and a microphone **152**. The transmission/reception circuit **160** includes a demodulation section **160a**, a modulation section **160b**, a signal switching section **160c**, and a message recording section **160d**.

The antenna **150** is used in order to receive radiowaves which are output from a nearby base station and to transmit radiowaves to the base station. The demodulation section **160a** demodulates and converts a modulated signal which has been input via the antenna **150** into a reception signal, and outputs the reception signal to the signal switching section **160c**. The signal switching section **160c** is a circuit which switches between different signal processes depending on the contents of the reception signal. If the reception signal is a signal indicative of a received call (hereinafter referred to as a "call received" signal), the reception signal is output to the electromagnetic transducer **64**. If the reception signal is a voice signal for message recording, the reception signal is output to

the message recording section **160d**. The message recording section **160d** is composed of a semiconductor memory (not shown), for example. Any recorded message which is left while the cellular phone **61** is ON is stored in the message recording section **160d**. Any recorded message which is left while the cellular phone **61** is out of serviced areas or while the cellular phone **61** is OFF is stored in a memory device within the base station. The call signal generation circuit **161** generates a call signal, which is output to the electromagnetic transducer **64**.

As is the case with conventional cellular phones, the cellular phone **61** includes a small microphone **152** as an electromagnetic transducer. The modulation section **160b** modulates a dial signal and/or a voice signal which has been transduced by the microphone **152** and outputs the modulated signal to the antenna **150**.

Now, the operation of the cellular phone **61** as a portable communication device having the above structure will be described.

The radiowaves which are output from the base station are received by the antenna **150**, and are demodulated by the demodulation section **160a** into a base-band reception signal. Upon determination that the reception signal is a call received signal, the signal switching circuit **160c** outputs the signal indicative of a received call to the call signal generation circuit **161** in order to inform the user of the cellular phone **61** of the received call.

Upon receiving a call received signal, the call signal generation circuit **161** outputs a call signal. The call signal includes a signal corresponding to a pure tone in the audible range or a complex sound composed of such pure tones. When the signal is inputted to the electromagnetic transducer **64**, the electromagnetic transducer **64** outputs a ringing tone to the user.

Once the user enters a talk mode, the signal switching circuit **160c** performs a level adjustment of the reception signal, and thereafter outputs the received voice signal directly to the electromagnetic transducer **64**. The electromagnetic transducer **64** operates as a receiver or a loudspeaker to reproduce the voice signal.

The voice of the user is detected by the microphone **152** and converted into a voice signal, which is inputted to the modulation section **160b**. The voice signal is modulated by the modulation section **160b** onto a predetermined carrier wave, which is output via the antenna **150**.

If the user has set the cellular phone **61** in a message recording mode and leaves the cellular phone **61** ON, any recorded message that is left by a caller will be stored in the message recording section **160d**. If the user has turned the cellular phone **61** OFF, any recorded message that is left by a caller will be temporarily stored in the base station. As the user requests reproduction of the recorded message via a key operation, the signal switching circuit **160c** receives such a request, and retrieves the recorded message from the message recording

section **160d** or from the base station. The voice signal is adjusted to an amplified level and output to the electromagnetic transducer **64**. Then, the electromagnetic transducer **64** operates as a receiver or a loudspeaker to reproduce the recorded message.

Many electromagnetic transducers incorporated in portable communication devices, such as conventional cellular phones, have a high resonance frequency, and are therefore only used for reproducing a ringing tone.

However, the electromagnetic transducer according to the present invention can have a low resonance frequency. When incorporated in a portable communication device, the electromagnetic transducer according to the present invention can also be used for reproducing a voice signal, so that both a ringing tone and a voice signal can be reproduced by the same electromagnetic transducer. Thus, the number of acoustic elements to be incorporated in the portable communication device can be effectively reduced.

In the illustrated cellular phone **61**, the electromagnetic transducer **64** is mounted directly on the housing **62**. However, the electromagnetic transducer **64** may be mounted on a circuit board which is internalized in the cellular phone **61**. An acoustic port for increasing the sound pressure level of the ringing tone may be additionally included.

Although a cellular phone is illustrated in Figures **10** and **11** as a portable communication device, the present invention is applicable to any portable

communication device that incorporates an electromagnetic transducer, such as a pager, a notebook-type personal computer, or a watch.

The second housing **10** or **20** for supporting the second magnet **9** or **29** is employed in Example 2 or 3 of the present invention. However, when the electromagnetic transducer **2000** or **3000** according to Example 2 or 3 of the present invention is to be mounted in the cellular phone **61** shown in Figure **10**, for example, the second magnet **9** or **29** may be embedded in the housing **62** of the cellular phone **61**, so that the housing **62** of the cellular phone **61** acts as the second housing **10** or **20**. Moreover, the second thin magnetic plate **24** of the electromagnetic transducer **3000** may similarly be provided on the housing **62** of the cellular phone **61**.

INDUSTRIAL APPLICABILITY

In accordance with an electromagnetic transducer of the present invention, an opening is formed in a central portion of a second diaphragm, and a center pole is provided so as to penetrate through the opening, so that a distance that forms a magnetic path between the second diaphragm and the center pole can be reduced as compared to those in conventional electromagnetic transducers. As a result, a sufficient driving force for causing a first diaphragm to have a large amplitude can be obtained, thereby enabling reproduction with a high sound pressure level.

In accordance with an electromagnetic transducer of the present invention, a first thin magnetic plate on a face of a first magnet opposing the first diaphragm,

thereby allowing an alternating magnetic flux to efficiently flow into the second diaphragm. As a result, a large driving force is provided, thereby making for a high sound pressure level.

In accordance with an electromagnetic transducer of the present invention, a second magnet is provided above the second diaphragm with a magnetic gap therebetween, thereby allowing the first diaphragm to be maintained in a state of equilibrium. As a result, a large driving force acting on the second diaphragm is provided. Since a substantially linear relationship exists between the attraction force and the displacement characteristics of the first diaphragm, it is possible to realize reproduction with a high sound pressure level and low distortion. By further providing a second thin magnetic plate above the second magnet, the second magnet can be allowed to efficiently function can be downsized in shape.

In accordance with a portable communication device incorporating an electromagnetic transducer of the present invention, it is possible to reproduce an alarm sound or melody sound as well as voices and the like with the portable communication device.